SMART PILLOW

Team 50 ECE 445 Final Report

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Abstract

This paper looks into the design process and results of the project "Smart Pillow", an advanced pillow that was developed to help track sleep and promote good sleeping habits. This paper presents an overview of the design process and outcomes of the system, including an analysis of the challenges that Smart Pillow aims to address. The paper explores various design alternatives and discusses the requirements and verification processes for the system's subsystems. In addition to this, the paper covers the project's parts, and labor aspects, summarizes its accomplishments, and finally concludes with potential future improvements.

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1. Introduction

1.1 Purpose

1.1.1 Problem

As technology advances, more people tend to use devices such as their phones or laptops right before going to bed. Studies have shown that sleep is affected drastically due to the use of technology in the hour before going to bed. This is mainly due to the blue light that is produced by the screens of these smart devices. The blue light produced has been known to interfere with the production of melatonin (the sleep hormone) in the body. This can result in less satisfactory sleep which causes people to be sleepier and more fatigued during the day. Some studies have also shown that bright screens can have an impact on alertness which can lead to users having disrupted sleep more often. Repeated dissatisfactory and disrupted sleep can lead to conditions such as sleep apnea. This is a growing concern due to the increase in the use of technology and can be dangerous.

The signs that a person is not having satisfactory sleep can be loud snoring and frequent changes in sleeping positions. One way that can improve sleep is by listening to relaxing music or some peaceful podcasts. However, you cannot be sure when you would be having disrupted sleep. Smartwatches do a good job of detecting your sleep cycle but they must be charged very often and they are not able to help you improve your sleep.

1.1.2 Solution

To fix the above-stated problems, we propose the implementation of a smart pillow. Through this smart pillow, we aim to not just track sleeping habits, but also improve them. We will track the sleeping habits of the user through the following sensors: touch sensor, audio sensor, and pressure sensor. In addition to these sensors, we will also use a Bluetooth speaker that can play white noise or any other sounds/music that the user feels comfortable with to aid sleep.
The audio sensor will be used to detect snoring which will provide us with insight on the quality of sleep of the user and potentially also detect sleeping disorders like sleep apnea. The touch sensor will be used together with the pressure sensor to determine the various sleeping positions of the user. This will then help us determine the quality of sleep of the user at each sleeping position.

We believe that our idea stands out from what is already available today through the usage of the Bluetooth speaker system and the fact that this is more cost-effective. Most devices that are currently available include mattresses and smartwatches. We believe that this is the feature that sets us apart from the other technology that is currently available in the market such as smartwatches and mattresses.

We will be using a power system to regulate the power of each sensor subsystem. Hence we will have to use a PCB since it will contain all the logic related to the sensors and the power modules. We believe that our product is a cost-effective and more versatile alternative to the current products available on the market.

1.2 Functionality

1.2.1 High-Level Requirements

1. The pillow should be able to detect motion when the person is in contact with the surface of the pillow.
2. There should be no interference in the data collected by the sensors from other components of the pillow (for example the Bluetooth speaker should not interfere with the working of the audio sensor).
3. The pillow should be comfortable, which means that the user should not be able to feel the sensors when they touch their head to the top of the pillow
4. The front and back of the pillow should be clearly differentiated so the data from the pillow is actually usable.

1.3 Design and Subsystem Overview

1.3.1 Physical Design

Fig 1: Side View of the pillow

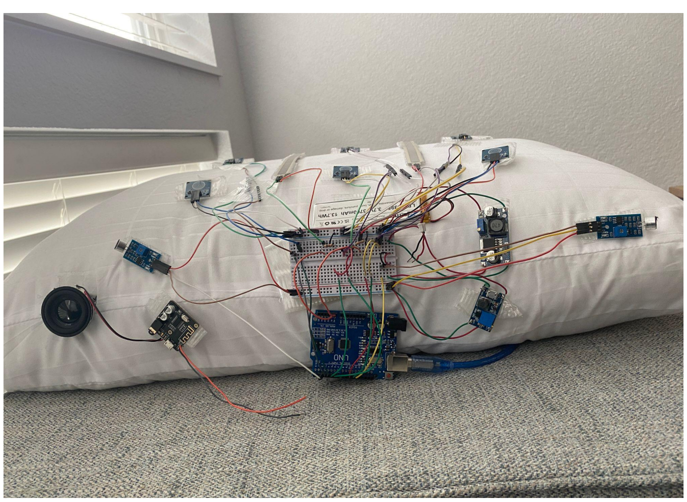
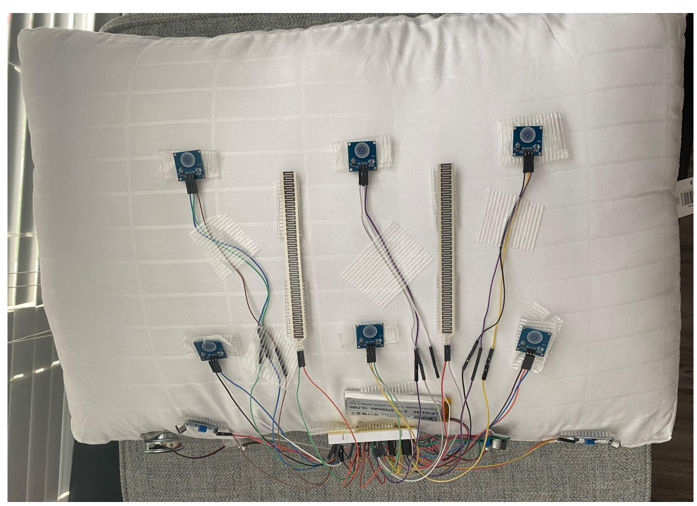
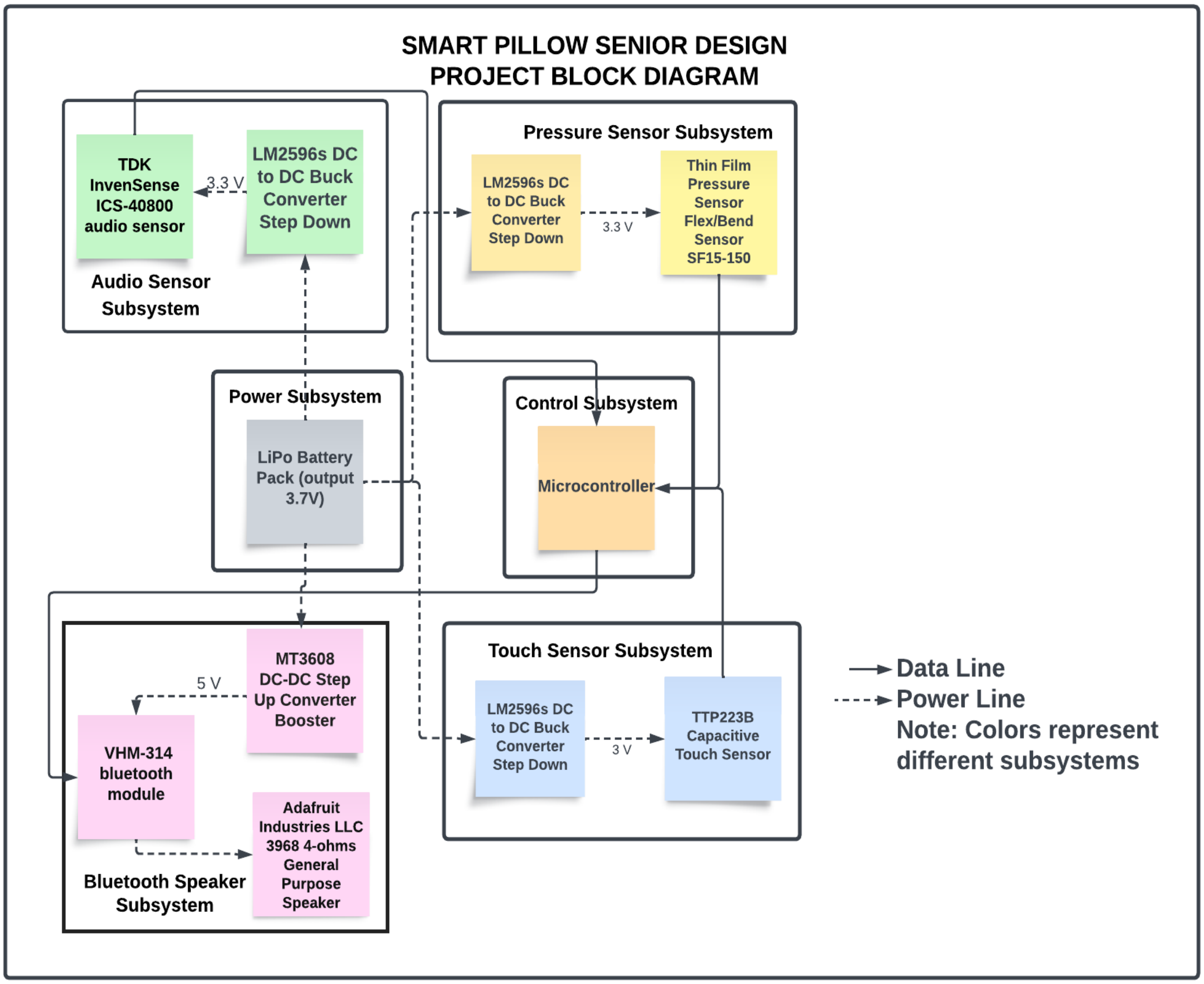


Fig 2: Top View of the pillow



1.3.2 Block Diagram

Fig 3: Block Diagram showing each subsystem and their connections



1.3.3 Subsystem Design

As is visible through our block diagram, we have 6 subsystems. There were multiple reasons behind this division. The primary reason was the ease of division. Having a greater number of subsystems increased our ability to divide work between the team. It also helped us divide up the resources, such as time and money, effectively. Additionally, having each sensor as a different subsystem improved the modularity of the design. This meant that we could add or remove any component of the smart pillow without affecting the rest of these components. At the heart of our design, we have our control and power subsystems. We designed it such that every subsystem has its own individual connection to these subsystems ensuring that they do not interfere with one another.

2. Design

2.1 Subsystem Overview

2.1.1 Power Subsystem

For the power subsystem, we will consider 5 parts that may require different power sources. These parts are (but are not limited to):

1. The pressure sensor subsystem
2. Touch sensor subsystem
3. The speaker (power here will be provided to the Bluetooth module and through that to the stereo amplifier unit and speakers)
4. The audio sensor subsystem
5. The control subsystem

To ensure that the pillow remains light and comfortable we have decided to consider using Lithium Batteries. These are usually lightweight and are used in a variety of medical devices ensuring that they will be safe for use. Additionally, they have good capacity, and sufficient voltage for the sensors we plan on using (thin film pressure sensors and audio sensors). Doing some further research into flexible batteries we noted that most of the reported flexible batteries are based on flammable organic or corrosive electrolytes, which suffer from safety hazards and poor biocompatibility for devices (Stapleton)[1]. Hence, we have gone for the more rigid lithium-ion batteries as alternative sodium-powered batteries are too expensive for a project of this scale. To ensure that we can make the system as modular as possible we plan on using Lithium Polymer batteries.

2.1.2 Control Subsystem

This subsystem will mainly be used to collect and transmit data between our different sensor subsystems. This subsystem will be responsible for collecting data from all our sensors such as audio, pressure, and touch, and will be able to signal the Bluetooth speaker to play music to improve the user's sleep. It will consist of the ATmega328P microprocessor which will be responsible for collecting data regarding head positions, head pressure, and snoring. Here, the data will be processed to determine if the person is having bad sleep or not. If the person is, then data is transmitted back to the microcontroller which will signal the Bluetooth speaker subsystem to play music.

Figure 4: PCB Design Back

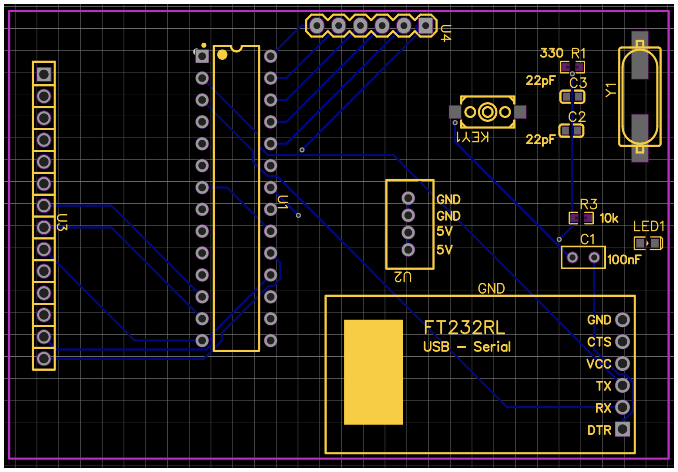
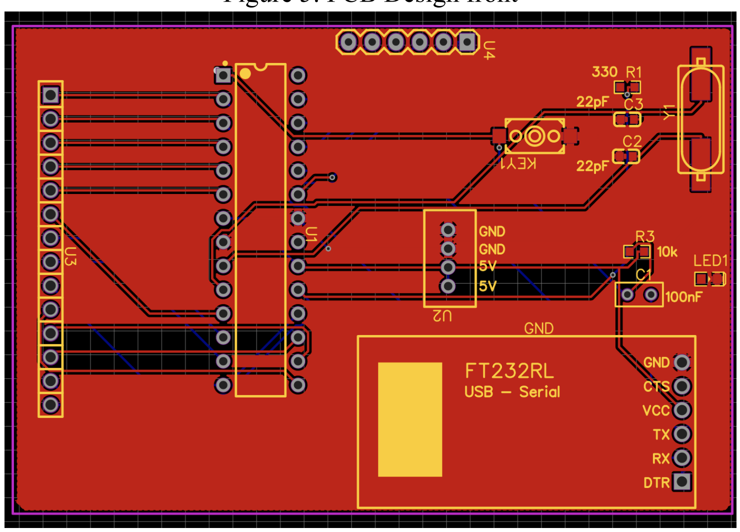


Figure 5: PCB Design front



The main goal of our PCB was to program our microcontroller (ATMega328P). The different components on the PCB were to ensure the microcontroller is programmed properly and we are able to get data out of the microcontroller regarding the different sensors. The FT232RL USB - Serial board on the PCB was mainly used to program the microcontroller. The Crystal oscillator along with the Capacitors at the top right corner of the PCB was used to give the microcontroller a clock signal, to ensure the correct programming of the chip. Even though we were able to program the microcontroller, we were unable to receive data from it. Hence, we used an Arduino Uno board with the same microcontroller to get data out of our sensor subsystems and send signals to the Bluetooth speaker subsystem.

2.1.3 Pressure Sensor Subsystem

This subsystem will mainly detect changes in pressure when a person is sleeping on the pillow. Usually, the pressure due to one's head can be used to determine the quality of sleep. People that tend to have poor sleep tend to put higher pressure on the pillow. Along with this, changing head positions very often can be a sign of bad sleep. Thin Film Force or Thin Film Pressure sensors SF15-150 Resistance will be used to detect changes in pressure and changes in head positions. One Thin Film Pressure sensor is 3.9 inches long, 0.4 inches wide, and 0.25 mm thick. Given the length and width of each sensor, we would be using 5-6 such sensors and placing them vertically across the pillow as shown in the visual aid. Each sensor would require around 3.3V to run. Since our power supply is 3.7V, we would be using LM2596s DC to DC Buck Converter Step Down Converter to get the desired voltage for the pressure sensor.

The use of multiple sensors will help us detect the different head positions of the person (which will be calibrated beforehand). The multiple sensors will also ensure the accurate detection of pressure applied to the pillow while sleeping.

2.1.4 Touch Sensor Subsystem

This subsystem will work in conjunction with the pressure sensors. Since the pressure sensors are strips, they would not cover the entire pillow. We will be using multiple small touch sensors that would be placed between two pressure sensors. The main aim of using the touch sensor is to detect the location of the head on the pillow because as mentioned earlier, head positions can help determine if a person is having bad sleep. Along with this, our goal is to try to use the touch sensors as a way to activate and deactivate other sensors to save power for our entire device. The dimensions of the touch sensor that we would like to use would be 24x24x7.2 mm. Each sensor would require around 3 volts to run. Since our power supply is 3.7V, we would be using LM2596s DC to DC Buck Converter Step Down Converter to get the desired voltage for the touch sensor.

2.1.5 Audio Sensor Subsystem

This subsystem will be used to detect sounds such as snoring. Snoring is the most common sign of disturbed sleep and sleeping disorders such as sleep apnea. For the use case of this project, we will be making use of two audio sensors so that we are able to detect any sounds produced by the user. We will be utilizing the TDK InvenSense ICS-40800 audio sensor for our device. It has a sensitivity of -38dBV and Signal to Noise ratio of 70dBA. We believe that these specifications will be adequate enough to detect sounds such as snoring which typically range from 45-60dB. The dimensions of each sensor are 4x3x0.97mm and require 155uA to run. Since our power supply is 3.7V, we would be using LM2596s DC to DC Buck Converter Step Down Converter to get the desired voltage for the audio sensor. ("ICS-40800 TDK InvenSense | Mouser")

2.1.6 Bluetooth Speaker Subsystem

This subsystem can be broken up into 3 main parts: The connection from the power subsystem, the Bluetooth module, and the speakers. To ensure that the speakers get the right amount of power to function at a higher level, a voltage booster will be required. Hence we plan on using a step-up converter to convert the incoming 3.7V from the power source (the LiPo batteries) to the 5V that the system can utilize. To accomplish this, an MT3608 DC-DC Step Up Converter Booster (Electronic Co, Ltd.) will be used. The potentiometer on the booster will allow us to adjust the output voltage to 5V. The next step is to find and use the correct Bluetooth module. This means one that combines a Bluetooth receiver with a stereo amplifier and decoder, enabling us to both receive and play the song using only one chip. The choice for this is the VHM-314. This Bluetooth board offers Bluetooth 5.0 connectivity and comes in at a small size of 3cmx3cm which is something that we can easily fit into our design. The board will receive power from the PCB connection and will only be powered when the audio sensor is not in function. Finally, this Bluetooth board will be connected to a single speaker. The Adafruit Industries LLC 3968 4-ohms General Purpose Speaker is an ideal choice because it has a lower power rating of 3W and an ideal size (40mm diameter). To summarize, the main components of the design will be in the middle of the pillow with the speaker being at the back for comfortable hearing.

2.2 Verifications

2.2.1 Power Subsystem

This subsystem was used to supply power to all the other sensor subsystems and the control subsystem. We required the LiPo battery to supply 3.7V. We were able to verify this by using a multimeter. In addition to this, we wanted to ensure that the user would not be able to feel the battery while using the product. We wanted to make sure that the battery pack was within the following dimensions: 35x100x15 mm and should weigh less than 80g. We were able to meet this requirement by selecting a battery pack with the following dimensions: 33.5x96x10.3 mm and weighed 74g.

2.2.2 Control Subsystem

The control subsystem was used to collect and process data from each of the sensor subsystems. Using the data collected from the sensors, the microcontroller would determine if the user was having disturbed sleep. The first requirement was to determine if the user was snoring. If the data received from the audio sensor was 1, the user was determined to be snoring. Next, for the touch sensor: We wanted to be able to identify if the user was changing positions every 30 seconds. This was done by analyzing the data from all six touch sensors. If all touch sensors gave us a value of 1, we were able to conclude that the user was changing positions every 30 seconds. Our last requirement was to be able to determine if the user was applying high pressure on the pillow while sleeping. Through our testing process, we were able to determine that a reading of 1300 from the sensors would indicate that the user is applying high pressure on the pillow.

2.2.3 Pressure Sensor Subsystem

This subsystem was able to work with the touch subsystem to determine the amount of pressure applied by the head and the motion on the pillow. Our first requirement was to ensure that each sensor was priced below $12 to ensure that we stayed within the budget. This was verified by comparing the different prices of the sensors from different vendors and only buying the required amount of sensors. Next, we wanted each pressure sensor to be less than 7.62mm thick to ensure that we maintained the comfort of the pillow for the users. This was verified by using thin film pressure sensors. We also wanted to keep our two pressure sensors 120.11mm apart from each other to ensure accurate readings of the head pressure. We were able to verify this by accurately measuring the distances before placing the sensors. The last requirement we had was that each pressure sensor should only receive 3.3V instead of the 3.7V supplied by the battery. We were able to verify this by using an LM2596s DC to DC Buck Converter Step Down Converter. We then tested the voltage being received by each sensor by using a multimeter.

2.2.4 Touch Sensor Subsystem

This subsystem was able to work with the pressure subsystem to determine the head positions and motion on the pillow. One of the requirements we had for this subsystem was that we must ensure the comfort of the pillow by using touch sensors with dimensions equal to or lesser than 24x24 mm and should have a thickness of not more than 7.2 mm. This was verified by comparing different touch sensors that were available in the market and choosing the one that matched our requirements. The second requirement we had was to have 2 touch sensors should be placed at equal distances for each pressure sensor, at least 60 mm from each. Since we had 2 pressure sensors, the pillow was divided into 3 sections, and 2 touch sensors were placed in each section. We verified this distance by measuring the distance using a ruler and placing the touch sensors accordingly. The third requirement was to be able to determine head positions using the 6 sensors. As mentioned, the pillow was divided into 3 sections. The way we were able to determine head positions was by checking how many and which touch sensors were turned on when the pillow was in use. When the center and left or center and right sections were on, this means that the user is sleeping on their side. If the center section was on and the others were off, then this means that the person is sleeping with the back of their head on the pillow. The final requirement we had for this subsystem was to use it to activate and deactivate the other sensors on the pillow to save power. However, we were unable to achieve this because there was no way for us to turn off the sensors or control the power supply to the sensors.

2.2.5 Audio Sensor Subsystem

This subsystem was responsible to detect sounds from the user such as snoring. One of the requirements we had for this subsystem was to ensure the comfort of the pillow by having audio sensors with dimensions of 5x5x1 inches and weighing less than an ounce. We ensured this by comparing different audio sensors that were available in the market and choosing the one that matched our requirements and was within our budget. The second requirement was that the speaker subsystem does not interfere with the data collection of the audio sensor. We ensured this by having a 10-second delay between the white noise played by the speaker and the next data collection by the audio sensor. The third requirement we had was that the sensor would receive exactly 5V instead of 3.7V from the battery. The sensors we chose for this subsystem needed a minimum of 5 volts to work accurately. To ensure the sensor gets this, we used a DC-DC step-up converter and tuned the converter to output 5V from 3.7V. The output was constantly checked using a multimeter. The final requirement we had was that the subsystem would be able to detect sounds as soft as 40 dB. However, we were unable to achieve this. Our audio sensors were not able to determine the decibel levels of the sounds it detect. Given the budget constraints, we were unable to use audio sensors that were able to detect decibel levels.

2.2.6 Bluetooth Speaker Subsystem

This subsystem was responsible for playing white noise when the control subsystem triggers the speaker when it detects that the user is having bad sleep. One of the requirements we had for this subsystem was to ensure the comfort of the pillow as the other subsystem by using a speaker with dimensions lesser than 45x45x40mm. To do this, we used the VHM-314 Bluetooth module which is 3x3cm, and the speakers with a diameter of only 40mm. The second requirement was that the speaker subsystem does not interfere with the data collection of the audio sensor. We ensured this by having a 10-second delay between the white noise played by the speaker and the next data collection by the audio sensor. The third requirement we had was to have smooth Bluetooth connectivity enabled by Bluetooth 5.0. We ensured this by using a VHM-314 which offers Bluetooth 5.0 connectivity. Our final requirement was to have a sound quality of over 3-ohm impedance and the ability to decipher what is played. However, we were unable to achieve this due to budget constraints. A speaker with good sound quality is usually extremely expensive and we needed to spread out of budget across all subsystems, and not just the Bluetooth speaker subsystem.

2.3 Software Design

The software for our project was split into two parts. The Arduino-related sensor software and the data collection and analysis of Python code.

2.3.1 Arduino Code

To delve deeper into the Arduino software, our plan was to connect our sensors to an ATMega328p bootloader with Arduino. This would enable us to communicate with the sensors and open up data in the port. We connected our Touch and Audio sensors to the digital pin outputs and the pressure sensor to the analog pin output. This was because the touch and the audio sensors only output 1 or 0 depending on whether or not they were active high. The pressure sensor on the other hand gave us readings for the value of pressure being applied. The Arduino code also utilized the millis() library from Arduino to include a timestamp. To explain this further, the timestamp is just a value in milliseconds for when that particular set of sensor data is collected from the time of opening of the Arduino serial port.

2.3.2 Python Code

The Python code was split into 3 main files, one to collect and read the data, one to analyze and graph the pressure and audio values, and one to graph the head positioning on the pillow.

Although the Arduino code printed the data onto the Arduino serial monitor, it was more important to get the data into an easy-to-analyze format, such as a CSV file. To do this, python opened the port to the connected module and read each line of the incoming sensor values. It split them by a comma and added that entire line into a new CSV file. As a precautionary measure, when the code would begin executing it would let the user know that it had successfully created the file and then would continue on its data collection. Additionally, it would also record the exact time of the opening of the port as the Python code was running on a laptop or device connected to the internet. The timestamp for each data reading coming from the Arduino code was then added to this data to get the exact time when the data was collected. This file also checks in real-time if the pressure reaches a particular threshold value and plays white noise to help the user sleep better by employing Python's winsound library.

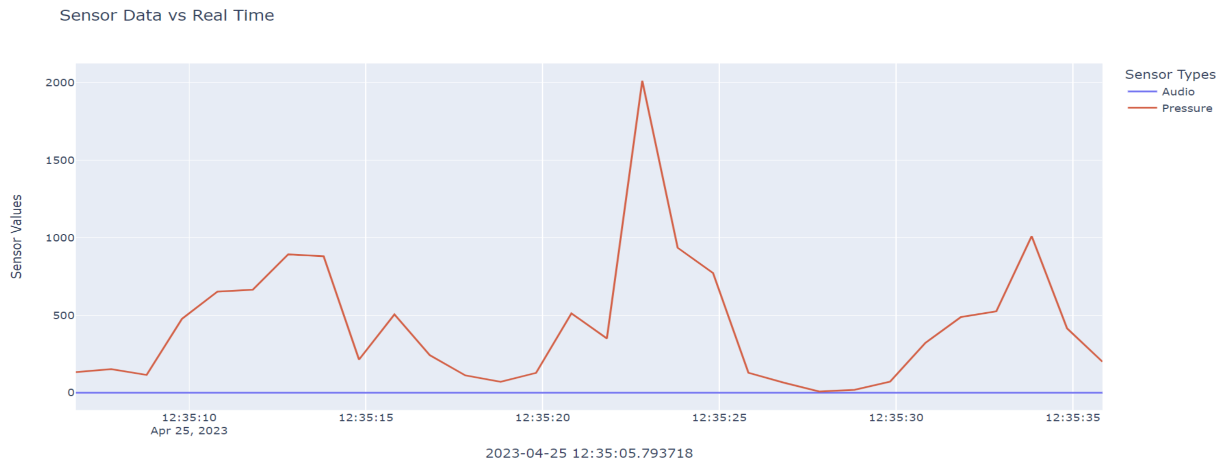
The next file for data analysis of the pressure and audio sensors uses the Python pyplot library. This code extracts the data from the CSV file generated by the data collection code described above. It converts the required columns into pandas dataframes and then plots them in an interactive graph that also gets saved locally as an html page so the user can refer back to it at a later point. This allows the user to see when they were having unsatisfactory sleep through the night by hovering over the graph and seeing the times corresponding to peaks in each graph.

The last file utilizes data from the touch sensor to accurately detect sleep positioning. This was done by assigning each touch sensor a unique ID based on its location. The data collection code then ran logic to determine a position based on which sensor was activated. The code is allowed to pick from 5 positions, and outputs motion if all touch sensors are activated or Not enough data if only one sensor is activated. This file utilizes this data to then create an interactive scatter plot using the pyplot python library.

Both of these plots are useful as together they paint a complete picture of the user's sleep quality. Noticing peaks in the pressure and audio sensor graphs and looking at their sleep positioning at those particular times will help the user get an insight into what positions negatively affect their sleep and why they are fatigued the next morning.

2.4 Result Graphs

Fig 4: Pressure Vs. Time graph, a screenshot of an interactive graph of pressure sensor data



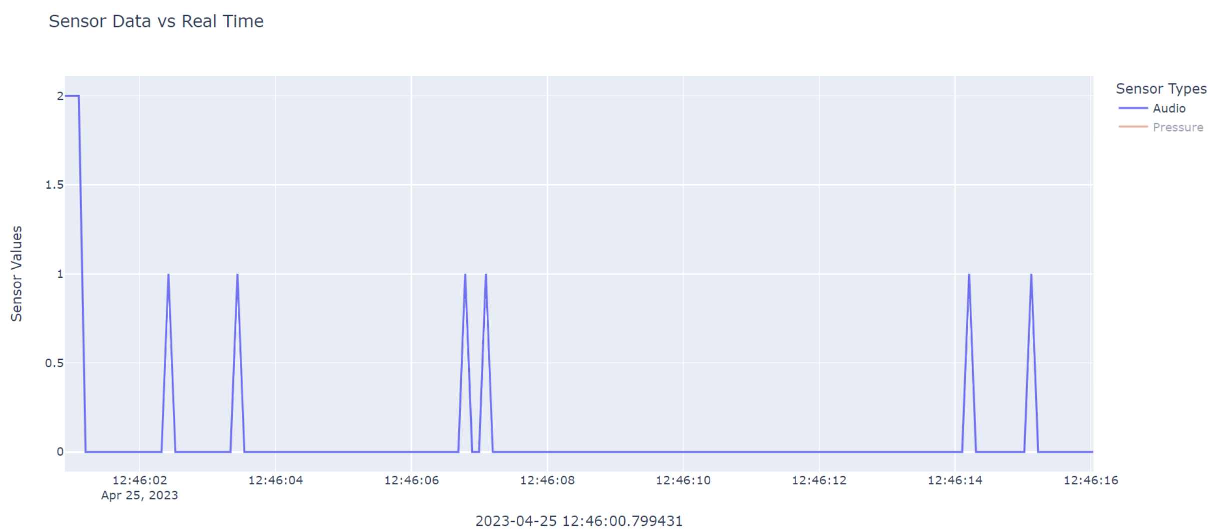
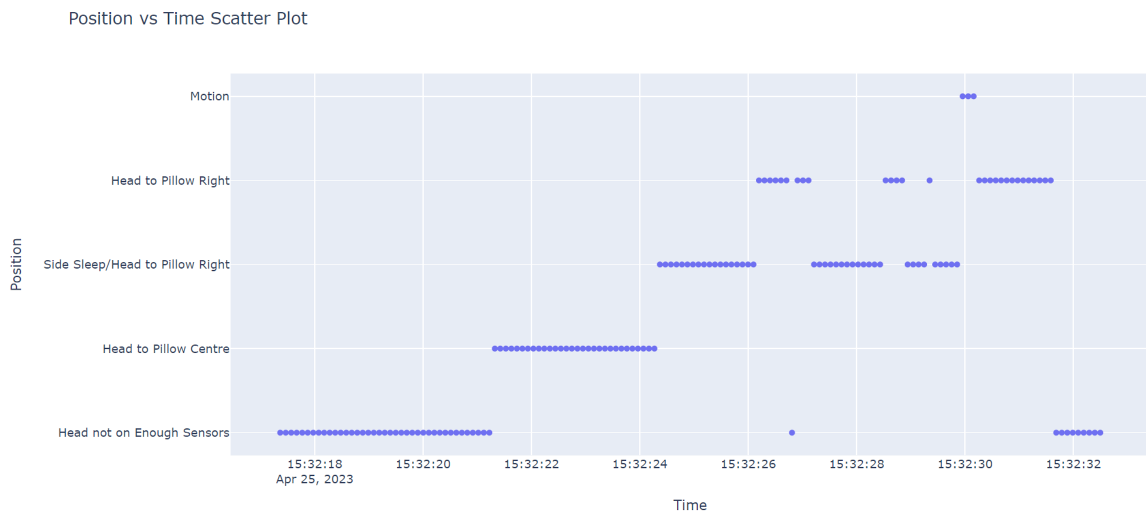


Fig 5: Audio Vs. Time graph, a screenshot of an interactive graph of audio sensor data

Fig 6: Position Vs. Time graph, a screenshot of an interactive graph of position using touch sensor data



3. Cost analysis

3.1 Parts

Table 1: Cost of components for the project

Component	Price Per Unit	No. of Units	Total Price
TDK InvenSense ICS-40800	$4.03	2	$8.06
Thin Film Pressure sensors	$10.70	2	$21.4
Touch Sensors (pack of 10)	$8.49	2	$16.98
LM2596s DC to DC Buck Converter Step Down Converter (pack of 2)	$9.99	1	$9.99
MT3608n DC-DC Step Up Converter Booster	$0.16	1	$0.16
VHM-314	$0.99	1	$0.99
Adafruit Industries LLC 3968 4-ohms General Purpose Speaker	$4.95	1	$4.95
Adafruit Micro-Lipo Charger for LiPo/LiIon Batt w/MicroUSB Jack - v1	$6.95	1	$6.95

EEMB Lithium Polymer Battery 3.7V 3700mAh 103395 Lipo Rechargeable Battery Pack	18.99	1	$18.99
Pillow	$5.48	1	$5.48
ATMega328P Microcontroller	$8.32	1	$8.32
TOTAL COST OF COMPONENTS			$102.27

3.2 Labor

According to research, an ECE graduate receives an average of $45/hr. Given that the expected number of hours spent on this project would be 80 hours, each member should receive an expected salary of 45*80 = $3600. So, the total expected salary for the whole team would be 3600*3 = $10,800.

If we are to make a rough estimate on the total cost of the components and labor, as seen from the values above, this comes up to **$10,902**.

4. Schedule

Table 2: Schedule that was followed for the project

Week	Tasks	Person
Feb 19 - Feb 25	1. Complete the Design document and team contract	Everyone
Feb 19 - Feb 25	2. Start working on the schematic of the PCB	Aniketh and Karan
Feb 19 - Feb 25	3. Order sensors and pillow needed for the project	Trusha
Feb 26 - March 4	1. Work on modifying PCB design	Aniketh and Karan
Feb 26 - March 4	2. Review PCB design at the Design meeting with the professor and TA	Everyone
Feb 26 - March 4	3. Work on Design Document review suggestion	Karan
March 5 - March 11	1. Work on finalizing PCB design	Everyone
March 12 - March	Spring break	

18		
March 19 - March 25	1. Design Document Review completion	Trusha and Aniketh
March 19 - March 25	2. PCB ordering after passing the audit	Everyone
March 26 - April 1	1. Finish soldering and testing of sensors 2. Make revisions to the PCB once testing of sensors is complete	Aniketh and Karan
March 26 - April 1	3. Start calibrating head positions 4. Order revised PCB (if needed)	Trusha
April 1 - April 8	1. Finish soldering new PCB	Karan
April 1 - April 8	2. Start testing sensors on revised PCB	Trusha
April 9 - April 15	1. Finalize the project by testing all sensors and components again	Aniketh
April 9 - April 15	2. Create the pillow with all the sensors attached 3. Begin testing of the entire pillow	Everyone
April 16 - April 22	1. Work on mock demo	Aniketh and Trusha
April 16 - April 22	2. Work on final presentation	Karan
April 16 - April 22	3. Complete mock demo	Everyone
April 23 - April 29	1. Make final changes to the projects after feedback from mock demo	Everyone
April 23 - April 29	2. Work on final demo	Aniketh and Karan
April 23 - April 29	3. Work on Final presentation	Trusha
April 23 - April 29	4. Complete final demo	Everyone
April 30 - May 6	1. Work on and complete final presentation 2. Complete final paper + lab notebook	Everyone

5. Conclusion

5.1 Accomplishments

All in all, we were able to comfortably achieve what we set out to do. We had a complete product that could detect the user's sleep and play white noise to improve it. Our project met all of the high-level requirements we set out to satisfy. The pillow should be able to detect motion when the person is in contact with the surface of the pillow. The pillow was deemed comfortable by everyone we tested it on, despite not having a foam-padded pillow cover. The users said they did not detect the sensors, which was a result of the choice of sensors and sensor dimensions we decided on. There was no interference in the data collection as whenever the speaker went off, the readings were paused for 10 seconds, allowing the noise to stop before the audio sensor detected new values. The front and back of the pillow were differentiated with the sensors lying flat on the pillow in the front. Finally, the pillow was able to detect motion when someone was in contact with the pillow with the help of the touch sensor readings and the data analysis code.

5.2 Uncertainties and Issues

We faced several issues while constructing and completing this project. These included but were not limited to - PCB functioning issues, budgeting challenges, and clock access.

Talking about the PCB functioning issues, we were able to successfully program our ATMega328P microcontroller. However, we were unable to extract the data that the microcontroller received from the sensors onto a laptop for processing. This was a critical part of our project because without the processed data, our microcontroller would not be able to decide when to trigger the Bluetooth speaker and we would not be able to plot our graphs. Due to this issue, we were forced to use an Arduino Uno to extract the data onto a laptop and to trigger the Bluetooth subsystem.

To elaborate on the budgeting challenges, we accounted for the initial cost of every item when presenting our design document. However, as time progressed, the cost of some of these items, particularly the thin film pressure sensors went up. Additionally, stores such as ali express which had the items for a lower value were only delivering them much later than our required date. This resulted in us having to reduce the total number of sensors used as we went from 7 pressure sensors to just 2, reducing the total data points we had for effective analysis. Additionally, we were also only able to afford audio sensors with threshold-driven activation, but having one with decibel level detection would have been more useful.

In regards to clock access, our control subsystem was not connected to the internet as that would have cost more than was within budget. As this was only required for the clock to see the real-time data collection, one reason did not justify the cost increase. To combat this issue we moved the collection of data into a Python script on an internet-capable device such as a laptop. This allowed the code to combine the real-time obtained and the time from start sent by the control subsystem into a real-time data value.

5.3 Future plan

We have several thoughts on how to move ahead with the product. First and foremost, we hope to get a foam casing for all the wiring and hardware towards the top of the pillow, covering up all the unnecessary mess and ensuring that the user does not have to worry about moving the wires, etc. Additionally, we hope to sew the sensors into the pillow to keep them in position and then cover the pillow with a padded pillowcase. Finally, to reduce the clutter of wires, the next step is to integrate all those components into a PCB, which can follow our PCB design schematic. Compiling all the code and making an interactive website or application would be the last step in our future plans for a more market-ready product.

5.4 Ethical Considerations

This project did not breach any ethical guidelines. This product is designed for those interested in improving their sleep quality. Throughout the development of this product, we plan to strictly adhere to the IEEE and ACM Code of Ethics. Safety will be the top priority of everyone involved in this project. Since our project is utilized in close proximity to the user's face and neck area, we used low-voltage components to ensure safety. Additionally, a Lithium Polymer battery was used for the system as these are generally used in medical devices. In addition to this, during testing, we did not collect or store any personal information of those involved. As engineers, we also have a commitment to sustainability. Through the development of this product, we attempted to optimize the part list as best as possible. This was accomplished by comparing different components and seeing which gave us the superior performance and the longest life span. Furthermore, as mentioned in the future plans, we aim to move the system to a PCB to avoid large chunks of wires and add a foam layer on top of the battery to ensure additional safety.

Appendix A

Table 1: Power Subsystem Requirement + Verification

Requirement	Verification
The DC power supply must provide a constant of 3.7 V within a 5% margin of error.	The output voltage of the DC power supply was measured using a multimeter to ensure that the voltage of the DC power supply is between 3.51 and 3.88 V.
Should be small and compact to ensure comfort while sleeping. The battery pack should be within the following dimensions: 35x100x15 mm and should weigh less than 80g.	The comfort of the pillow is extremely important for this project as individuals must be able to sleep on the pillow with ease. To ensure that this is the case, we will be using a Lithium Polymer battery pack which has the following dimensions: 33.5x96x10.3 mm and weighs 74g.

Table 2: Control Subsystem Requirement + Verification

Requirement	Verification
The control subsystem must be able to determine if the person sleeping on the pillow is snoring	This will be done by ensuring that data can be collected from the audio subsystem. If the decibel level detected by the audio subsystem is above 40dB, then the person is determined to be snoring.
The control subsystem must be able to determine if the person sleeping on the pillow is changing positions every 30 seconds	This will be done by ensuring that data can be collected from the touch subsystem. If the control subsystem receives data from various touch sensors, the person is determined to be changing positions.
The control subsystem must be able to determine if the person is applying high pressure on the pillow while sleeping	This will be done by ensuring that data can be collected from the pressure subsystem. If the pressure detected by the sensors is above 1300, the person is determined to be applying high pressure on the pillow.

Table 3: Pressure Sensor Subsystem Requirement + Verification

Requirement	**Verification**
Each sensor should be at a cost lower than $12.	The way we ensure that the sensors are cost-effective is by determining the length of the pillow and purchasing only the required amount of pressure sensor strips to cover the pillow. Along with this, we looked at many different vendors and compared the prices of the sensor in each to make sure we are buying the cheapest one available.
The thickness of the sensor should not exceed more than 7.62mm to ensure comfort while sleeping	To achieve this, Thin Film Pressure sensors were chosen to use in the pillow design. These sensors have a thickness that is significantly thinner than other types of pressure sensors available. To ensure this, we compared the thickness of different types of pressure sensors available and decided to go with the thin film pressure sensors since they have the lowest thickness.
The distance between each pressure sensor should be 120.11 mm to ensure accurate reading of the head position	The placement of the sensors is critical to get accurate and reliable data, as the spacing between sensors will impact the sensitivity of the measurements. If the sensors are placed too far apart, it can result in gaps in the data. Hence, to ensure this distance is maintained, the distance will be measured accurately beforehand.
Must only receive 3.3V instead of 3.7V from the battery	The way the voltage will be stepped down is by using an LM2596s DC to DC Buck Converter Step Down Converter. The way the sensor is receiving the required voltage will be tested is by using a multimeter and checking the voltage across the sensor.

Table 4: Touch Sensor Subsystem Requirement + Verification

Requirement	Verification
The dimensions of the sensors should not exceed more than 24x24 mm, and the thickness should not be more than 7.2mm to ensure the comfort of the pillow	Comfort of the pillow is extremely important for this project as individuals must be able to sleep on the pillow with ease. To ensure the size of the sensors, we compared the thickness and dimensions of different types of touch sensors available and decided to go with the touch sensors that match our requirements.
2 touch sensors must be placed exactly in the middle of 2 pressure sensors, and 2 on either side of the pressure sensors which means the distance between a touch sensor and a pressure sensor on either side must be around 60 mm.	To make sure that this is achieved, the distance on either side of the touch sensor to a pressure sensor will be measured and will only be placed once the distance of either side is the same.
Able to detect head positions when a person is sleeping on the pillow	Since the touch sensors will be placed all around the pillow, between pressure sensors, by mapping the positions of the sensors, the position of the head will be determined. At first, the sensors will be calibrated with different possible head positions. Later, when a person places their head on the pillow, due to the previously calibrated sensors, the head position can be determined easily.

Table 5: Audio Subsystem Requirement + Verification

Requirement	Verification
Small in size to ensure the comfort of the pillow. Dimensions of each sensor should be within the following: 5x5x1 inches and weigh less than 1 ounce.	Comfort of the pillow is extremely important for this project as individuals must be able to sleep on the pillow with ease. To ensure that the subsystem meets these requirements, we will be using 2 High Sensitivity Sound Microphone Sensor which has the following dimensions: 4 x 4 x 0.5 inches and weighs 0.63 Ounces. These dimensions are ideal since they are unlikely to disrupt the shape

	and comfort of the pillow.
Need to ensure that the audio sensors and the Bluetooth speaker do not interfere with each other.	We ensured this by having a 10-second delay between the white noise played by the speaker and the next data collection by the audio sensor
Must only receive 5V instead of 3.7V from the battery	The way the voltage will be stepped dowupn is by using a DC to DC Converter Step up Converter. The way the sensor is receiving the required voltage will be tested is by using a multimeter and checking the voltage across the sensor.

Table 6: Bluetooth Speaker Subsystem Requirement + Verification

Requirement	Verification
Small in size to maximize space for more important sensors. The diameter of the speaker should be less than 50 mm and the Bluetooth module is less than 5x5 cm	To achieve this and make sensors work well, the components for the speaker are small. The VHM-314 is 3x3cm and the speakers have a diameter of only 40mm.
Need to ensure that the audio sensors and the Bluetooth speaker do not interfere with each other.	We ensured this by having a 10-second delay between the white noise played by the speaker and the next data collection by the audio sensor
Cross-device connectivity enabled by Bluetooth 5.0	Our choice of the VHM-314 offers Bluetooth 5.0 connectivity and connects across all platforms.

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